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earthquake-triggering mechanisms

TERRESTRIAL SCIENCES LABORATORY, AFCRL

Tests of rock behavior under conditions of high temperature and pressure have suggested two new mechanisms that may trigger earthquakes. In a recent series of laboratory experiments using a large shear press, Dr. Robert E. Riecker of AFCRL found that the strength of a water-bearing mineral was drastically reduced when the mineral was dehydrated by heat. In another case, the crystal structure of a material changed suddenly under certain conditions. Dr. Riecker believes that such internal changes in rock structures, rather than their slippage along faults, may be the main cause of "deep earthquakes"--those originating below the earth's outermost layer or crust.

Geologists have realized for some time that the fault theory, though adequate to explain "shallow" earthquakes (those originating in the earth's crust), had severe shortcomings when applied to deep earthquakes. In the earth's mantle, where deep earthquakes originate, pressures of hundreds to thousands of atmospheres squeeze adjoining rock structures together too tightly for them to slip along faults. Under greater pressures, deformation of the rock structures would absorb these forces before slippage occurred. Laboratory measurements of the strength of rocks indicate that much greater forces are needed to deform rocks than are associated with deep earthquakes. But in the absence of experimental data, there was nothing to replace the fault theory as an explanation of deep earthquakes.

Such considerations led Dr. Riecker to study the behavior of silicate minerals, like those in the earth's mantle, at temperatures and pressures comparable to those found as deep as 200 km in the mantle. Eighty per cent of deep earthquakes originate in the region above 200 km. Previous studies of rock strength had mostly been conducted at lower temperatures and pressures. Only with AFCRL's high-temperature, high-pressure shear press has it been possible to simulate simultaneously the pressures and temperatures found in the earth's mantle.

In Dr. Riecker's hydraulic press, thin wafers of various minerals are squeezed between flattened tips of two tungsten-carbide anvils. Samples are heated by an induction coil. The strength of the samples is tested by slowly rotating the shaft on which one of the anvils is mounted. At low pressures, the flat tip of the rotated anvil slides across the sur-

face of the sample much like a slipping clutch. At higher pressures, however, friction between the two surfaces is too great for slipping to occur, and the internal structure of the sample is deformed by twisting. The shear stress which produces this deformation is the same type of stress present in the earth's interior, and provides a measure of the material's strength. With this press, Dr. Riecker has been able to measure the effects of shear stress on materials at pressures of 60,000 atmospheres and temperatures of 1000 degrees C--conditions more extreme than have been achieved in other laboratory tests of rock strength. These conditions correspond to a depth of about 200 km.

With the shear press, Dr. Riecker has examined the properties of a large number of minerals. Two of these proved of special interest. Each one suggested a mechanism for earthquake formation.

One of these is a greenish mineral called serpentine, a magnesium silicate that contains water molecules in its crystal lattice. Dr. Riecker found that, at temperatures above 500 degrees, the water is driven out of the serpentine's crystal lattice, thereby greatly weakening its ability to withstand stress. Indications are that other hydrous minerals, believed to exist in the earth's mantle, may undergo a similar weakening under conditions of high temperature. Thus an increase in temperature in a region of the mantle containing such materials could weaken them enough for existing shear stresses to trigger a cataclysmic deformation resulting in an earthquake.

The other material is a silicate mineral called enstatite. Dr. Riecker discovered that this mineral changes its crystal structure under certain conditions of temperature and pressure. This mineral has two different types of crystal structure. At temperatures

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between 500 and 700 degrees C, enstatite changes from one type of structure (from one phase) to another which occupies 10 per cent less volume. The particular temperature at which this phase change occurs depends on the pressure. However, Dr. Riecker discovered that this change could be brought about suddenly at much lower temperatures by applying a relatively small shear stress to the material. If such changes in crystal structure occur in materials in the earth's mantle, they could also trigger earthquakes.

★

The Oxidation of Clean Molybdenum Surfaces

DR. T. W. HAAS
Chemistry Research Laboratory, ARL

The refractory metals have many properties which suggest important uses in Air Force applications. One of their more important properties, strength at elevated temperatures, is offset somewhat by a tendency to oxidize at temperatures of interest. Very little is known of the initial stages of oxidation in these metals, although many studies have been carried out on the later stages. A study of the molybdenum (110) surface and its oxides has been carried out recently at the Aerospace Research Laboratories using low-energy electron-diffraction techniques (LEED)*. These studies have led to the determination of the structures of the clean (110) surface as well as the various oxide structures formed in the initial stages of oxidation.

The single crystals of molybdenum used in these studies were of extreme purity. Nonetheless, surface contaminants were present and had to be removed prior to LEED studies. The principal contaminant appeared to be carbon, which diffuses to the surface at elevated temperatures and forms various structures on the surface. Its removal was effected by heating the samples in an oxygen atmosphere. This oxidizes the carbon to carbon monoxide, which is subsequently desorbed. Heating alone is not adequate to remove this carbon contaminant. Heating in excess of 1000°C in an ultrahigh vacuum environment will remove molybdenum oxides, exposing the clean surface. A LEED pattern from a clean Mo (110) surface taken at 145 volts incident beam energy is shown in Figure 1. A marble model was made to

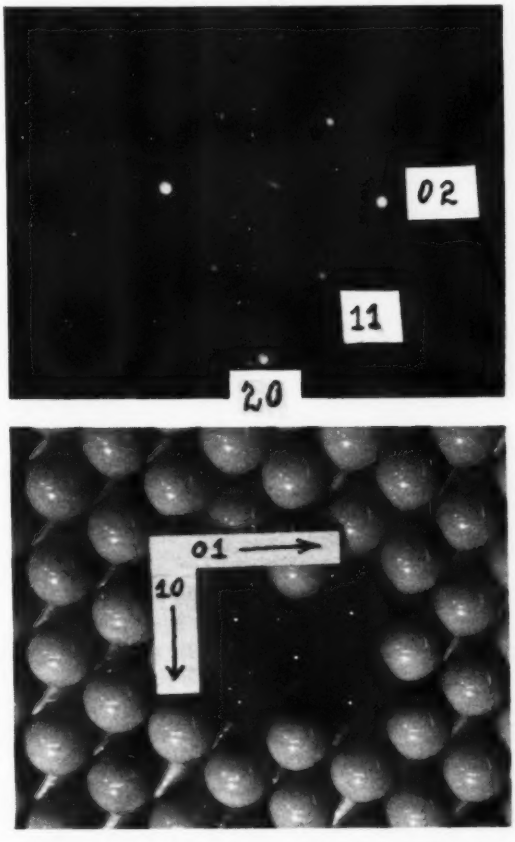


Figure 1. Diffraction pattern from clean Mo (110) surface taken at 140 V. Marble model shows a unit rectangular mesh (dark balls) as well as azimuth designations. Diffraction beams are indexed using these designations. Note absence of 01 and 10 reflections. Diffraction patterns and marble models are oriented so that a (110) crystallographic direction in the crystal is horizontal, while a (100) direction is vertical.

* *Low-energy electron diffraction was discussed in a recent article in the Review by M. Swerdlow (December 1965). Since the basic ideas of this technique were presented quite well in that article, these details are not repeated here.*

portray the arrangement of the molybdenum atoms; this model is shown below the diffractogram to aid in interpretation of the patterns. Directions in the crystal are indicated by the arrows on the marble model, and diffraction beams are indexed using these unit mesh vectors.

If the clean surface is exposed to an oxygen atmosphere, various oxide structures are formed, depending on the exposure. The first clear patterns correspond to 1/4 monolayer coverage. The diffraction pattern from such a structure is shown in Figure 2a, along with a marble model indicating a structure consistent with this diffraction pattern. Further exposure to oxygen produces new diffraction patterns corresponding to 1/2 monolayer coverage. This diffraction pattern, as well as a marble model showing the atomic arrangment, is shown in Figure 2b. Further exposure produces the 3/4 monolayer coverage shown in Figure 2c. Patterns due to higher coverages are also obtained, but have not been entirely explained as yet. In all cases these reactions were carried out at room temperature. At room temperature, the oxidation does not appear to go much beyond two layers of oxide even after long exposures to oxygen. Heating the sample to about 600° C causes growth of oxide layers on the surface. Figure 3 shows a pattern obtained after heating in oxygen. Epitaxial growth of oxides has certainly taken place, but the patterns obtained have not as yet been fully explained.

As regards kinetic considerations it would appear that, below one monolayer coverage at least, each oxygen molecule which strikes the surface is adsorbed and reacts. The reaction is sufficiently rapid so that no rate constants have been determined.

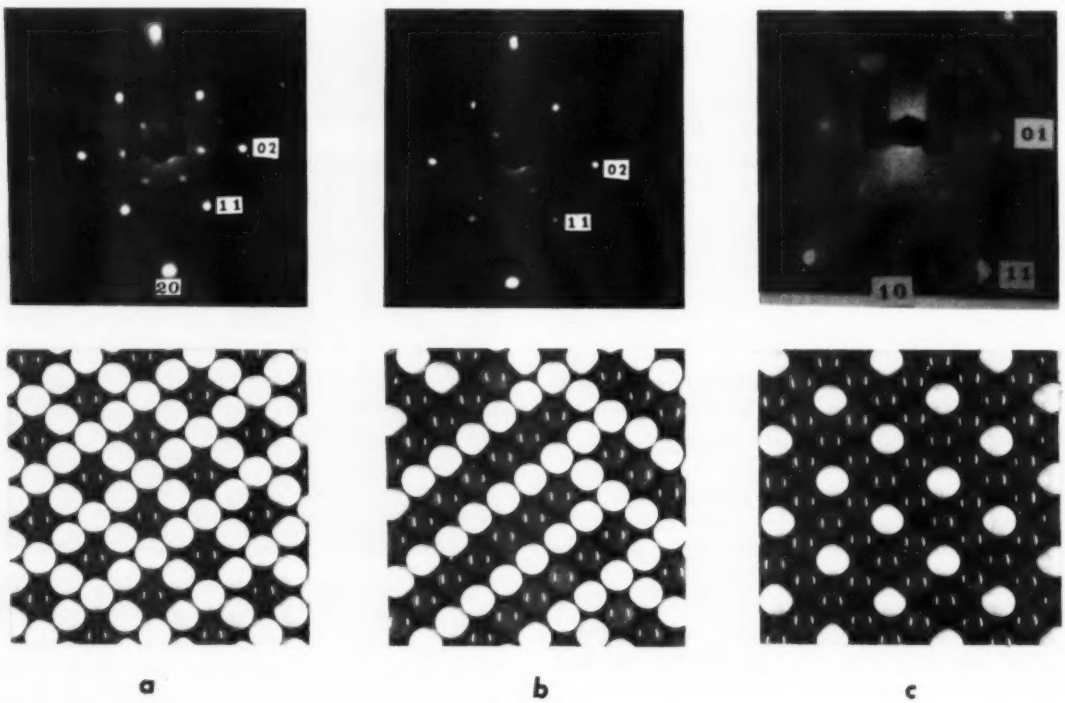


Figure 2. Patterns obtained after exposure to oxygen. a) 1/4 monolayer adsorbed; note presence of 01, 10 and 1/2 1/2 beams (140 volts); b) 1/2 monolayer coverage; note absence of 01 and 10 beams (140 volts); c) pattern due to 3/4 monolayer; note reappearance of 01 and 10 beams (95 volts). Dark balls represent oxygen atoms, light balls molybdenum atoms.

Figure 3. Photograph of diffraction pattern obtained after heating in oxygen (140 volts).

A number of outstanding problems in the use of LEED for these studies remain. Chief among these is adequate accounting for intensity variations of these beams. As such problems are overcome, LEED will doubtless be used more and more to obtain fundamental information about important solid-surface properties. ★

tailoring information systems to people

ROWENA SWANSON
Directorate of Information Sciences, AFOSR

People have memories, rather good ones. They can recall a yellow-covered book, a magazine with a particularly appealing cover, a graph in the upper right corner of a page, or the fact that some data were interpretively reviewed in a report read about six months ago.

People have nesting instincts. The housewife arranges food, clothing and jewelry in ways that help her find what she wants fairly quickly. The manager, the scientist, and the secretary try to do this too--but the number of items they have to file and find keeps growing. One day one might want to find everything Charles Slosh has ever said--but the next day only what he had to say about the neutrino together with what everyone else had to say during the period 1960-1962.

People have idiosyncrasies. They manifest some of the most idiosyncratic behavior with respect to information storage and retrieval. They keep their books in highly personalized arrangements. They file reports and tables and correspondence in ways that may be meaningful only to them. They have ways of putting together a sentence here with a numerical value there, and designing an entire experiment or building a theory based on what they synthesize from a few bits and their own mental store.

Information systems are supposed to be designed for people. They are supposed to be able to use ideas on how to arrange information, and devices for storing and manipulating marks to relieve people who use information from the necessity of also having to code and file it. Libraries have long done the collective job of serving a community of people. Books are easy to find in a library, either through card catalogs or knowing where groups of them are filed on shelves. But the library catalog is not usually so detailed as to tell everything about a Charles Slosh or about work on neutrinos during the period 1960-1962. This is what the new generation of storage-and-retrieval schemes, called "information systems," is supposed to do.

It would be possible to design an information system to serve a single person. This would be a rather expensive system, since it could require a system designer to observe the total information-gathering and using habits of that person. In addition, it could require a documentalist to establish a classification scheme for arranging and sorting the information, a subject specialist to read and evaluate the information, a coder and/or filer and/or machine for storing the information, and a reference librarian for retrieving it.

The practical approach for serving groups of people has been to establish information centers. The success of these centers in tailoring their services to the individual has varied. One of the outstanding networks of such centers is that at the Oak Ridge National

Laboratory (ORNL).[1] But the ORNL complex is the exception rather than the rule. If the system for the single person is not economically practical, and if the system for groups of people appears to be the necessary compromise, it becomes desirable to do what the system designer would do for the individual, i.e., try to assess individual practices and attempt to extrapolate from a sufficient sampling to satisfy group needs. This, in effect, is what has been done and is being done at ORNL, and is at least one of the reasons for the success of the ORNL centers.

This assessment is what is also being done for a more general population of scientists by Prof. Gerald Jahoda at Florida State University under AFOSR grant 895-65. Prof. Jahoda has sampled the individual information-gathering and storing behaviors of about 75 university professors and graduate students who are teaching and doing research. He is asking such questions as: How do you arrange your personal files? How do you index them? How do you use them? How often? How do you up-date them? Jahoda is also trying to integrate the information specialist with the information user to help them both. The hypothesis is that the information specialist can relieve the scientist from the time-consuming chores of journal and document scanning, indexing, and filing. But the scientist must learn to have confidence in the ability of the information specialist to select, sort, and file. The information specialist, in turn, cannot perform adequately unless he knows the behavior and interests of the scientist. Jahoda has set out to show that this interaction can work, and he plans to specify how it can work, based on data he is gathering in his experiment.

A further hypothesis relevant to information systems might also be made. This concerns the generalizability of Jahoda's data to the design of large-scale, machine-based systems that can accommodate various and varying needs of many users in such a fashion as to give each the impression that the system is tailor-made. The proof of this hypothesis depends not only on Jahoda's data, but also on the results of a number of studies being sponsored by AFOSR and other agencies. ★

(1) Several of ORNL's information centers are described in "Information Centers at the Oak Ridge National Laboratory (A Study in Diversity)," by Francois Kertesz, ORNL-TM-996, 13 Nov 64.

THIN MAGNETIC FILM LOGIC DEVICE

1ST LT WILLIAM F. KING, III, Data Sciences Laboratory, AFCRL

The quest for new and better devices for the construction of digital processors has often led to the possibility of an all-magnetic computer. Many of these attempts have failed because the device, even though it worked, was just not as simple to construct and operate as the transistor. Under AFCRL contract, the Laboratory for Electronics, Boston, Mass., has discovered a new magnetic phenomenon applicable to digital-computer technology that has the requisite simplicity of operation and construction. This phenomenon, known as domain-tip propagation, occurs in a thin ($\sim$1000 A^{o}) sheet of permalloy. Initially, the sheet is magnetized all in one direction much like an ordinary bar magnet. If a small magnetic field is applied in the opposite direction, regions of the sheet reverse the direction of magnetization. These regions of reversed magnetization grow across the sheet of permalloy in long thin spikes or tips at an approximate speed of 10^5 cm/sec.

If a thin sheet of aluminum is placed under a portion of the magnetic sheet, that portion of the sheet will not change direction of magnetization as easily as the rest of the sheet. If the sheet of aluminum is etched in a particular shape, the reversed domain will grow only along the etched regions of that shape.

Figure 1 shows a sheet of permalloy with the underlying aluminum everywhere, except in the channels. In this example, for small

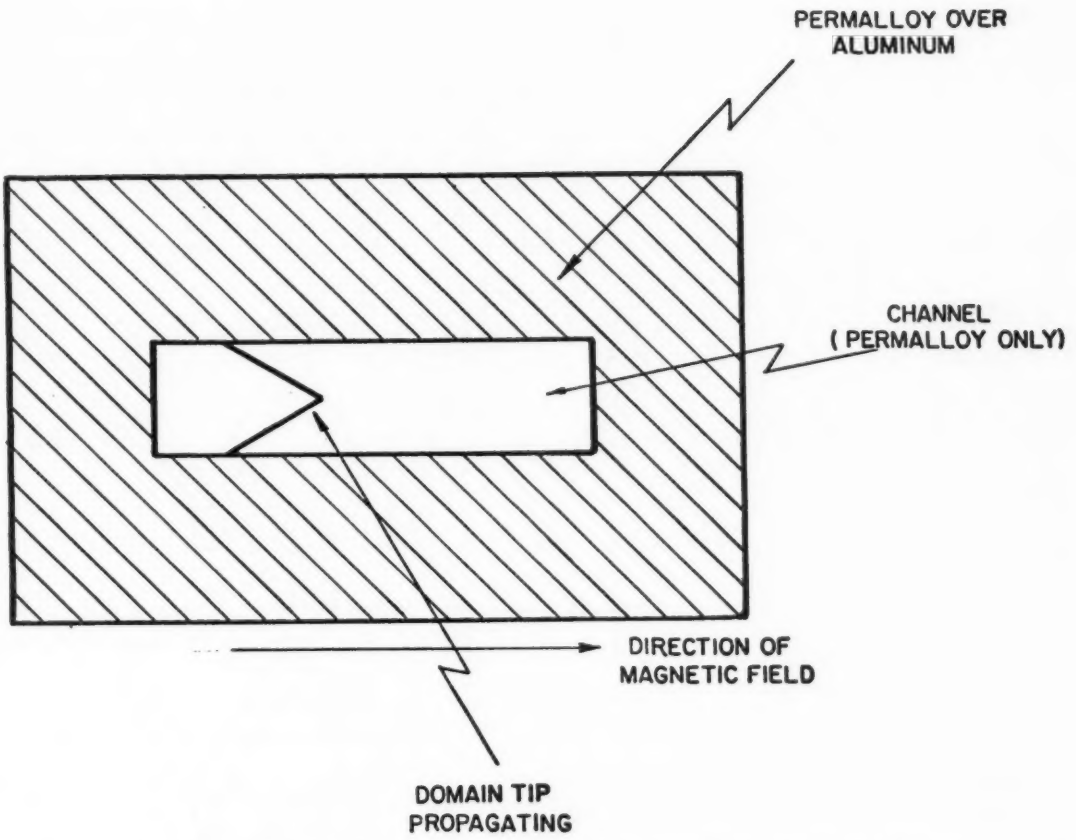


Fig. 1. Sheet of permalloy with underlying aluminum everywhere, except in channels.

magnetic fields, the magnetization direction of the permalloy would change only in the channels.

One application of domain-tip propagation is a shift register, i.e., a device that stores a number of bits of information and can shift the information from one location to another. The shift register shown in Figure 2 has the underlying aluminum everywhere, except in the zigzag pattern. One bit of information can be stored in every other vertex. The transfer of a bit is shown in Figure 2. In part (a), a bit of information is stored in a vertex of the shift register. It will now be transferred to the next vertex to the right. In part (b), a magnetic field is applied to grow the tip along the channel. Only the channel is reversed because of the underlying aluminum pattern. In (c), the channel is returned to its initial state except for a small tip at the bottom vertex. Now in (d), the tip in the bottom vertex is allowed to propagate in the next channel. Part (e) is the same as (c), and the operation is complete.

At the tip of a reversed region, there is a gradient of magnetization which gives rise to a magnetic field. The reversed region can be thought of as a bar magnet with north and south poles at the ends. The well-known principle of like poles repelling and opposite poles attracting is the basis for another application of the domain-tip phenomenon. The device shown in Figure 3 is a simple switch. If a tip is in the left-hand channel, no tip may pass by in the right-hand

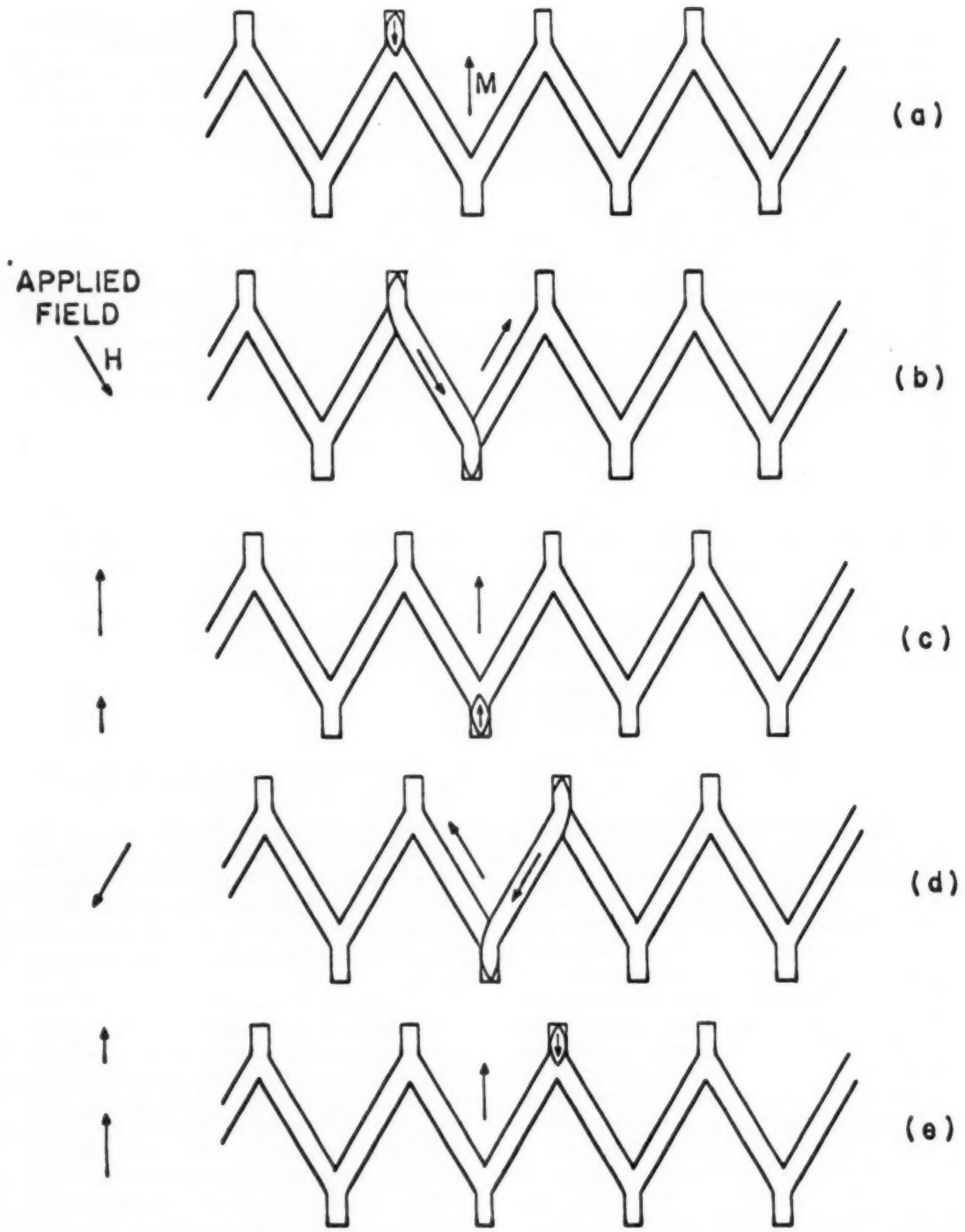


Fig. 2. Shift register with underlying aluminum everywhere, except in zigzag pattern.

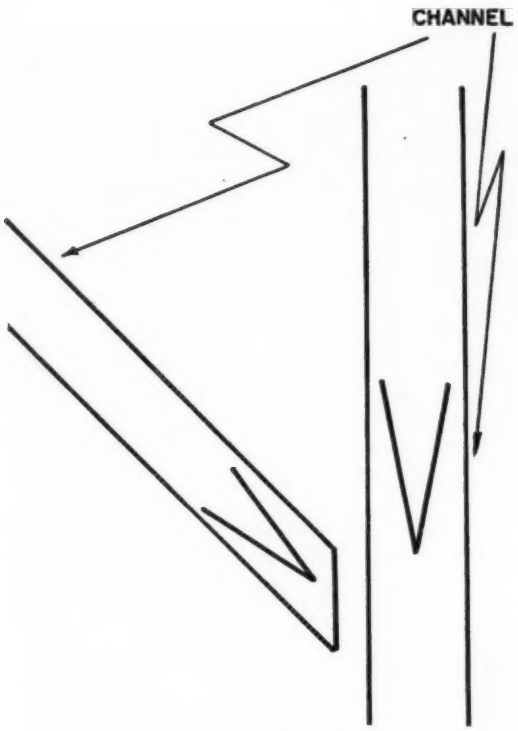


Fig. 3. Simple switch.

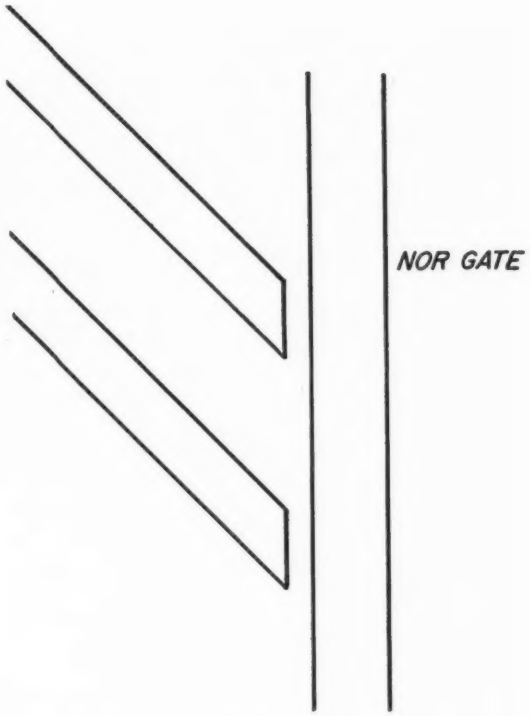


Fig. 4. NOR (logic) gate.

channel. Other more sophisticated arrangements of this type are possible (e.g., Figure 4 shows a NOR (logic) gate); thus, in principle, this enables one to construct an entire computer with these domain-tip propagation devices. ★

method for measuring vertical wind profile from aircraft

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

A system for measuring the vertical wind profile from an aircraft has been designed by James F. Morrissey of AFCRL. With this system, wind speed and direction at various altitudes could be obtained in remote areas where observations cannot easily be made--over oceans, for example.

The basic component is an expendable transmitter dropped from the airplane. Dropping things from aircraft is hardly a new technique for gathering weather information. The oldest and simplest example is the smoke bomb used to obtain a coarse measure of wind direction. More sophisticated is the "dropsonde" used to obtain vertical profiles of atmospheric temperatures and density.

Previous attempts to accurately measure wind speed and direction at all levels between an aircraft and the ground have centered around a parachute system which descended slowly enough to acquire the motion of the surrounding air. Tracking such systems from aircraft by some type of electromagnetic ranging system provided a vertical profile of wind speed and direction

relative to the aircraft. But in converting this to a profile of wind relative to the ground, large errors resulted from even small uncertainties in the aircraft's speed. The problem was to design a relatively simple, inexpensive sonde that operated on an entirely different principle.

Morrissey designed a free-falling sonde that is aerodynamically similar to a rocket. This sonde makes use of the familiar principle of weathercocking--the tendency of streamlined objects to align themselves with the wind. In the case of the sonde proposed by Morrissey, its rocket shape keeps its cylindrical axis vertical when it is falling through a region of no wind. Otherwise, it is tilted into the wind by an amount proportional to the horizontal wind speed. The degree of tilt is then determined by a slowly rotating accelerometer mounted in the sonde to monitor the angle between the cylindrical axis and the earth's gravitational field.

Such a system, of course, measures wind speed and direction only with respect to the sonde itself. A means to determine the orientation of the sonde with respect to the aircraft is also needed. This information can then be combined with the aircraft's heading to obtain wind speed and direction with respect to the ground. This is, after all, the desired end product.

The sonde's telemetry system can be made to serve a kind of double duty to provide this information. The sonde's directional antenna is rotated so that the signal received by the aircraft varies in strength in a regular way. As the antenna passes a particular point on the sonde, a tracer signal is added. The phase difference between the time this signal is received and the time the maximum signal strength is received indicates the orientation of the sonde with respect to the aircraft.

Wind speed and direction as a function of altitude are obtained by timing the sonde's descent and converting the timing data to altitude. Typical times of descent will be 5 to 10 minutes when the sonde is released from altitudes around 30,000 feet.

An operational device is expected to be available in about 18 to 24 months. ★

ROCKETS, ARECIBO RADAR & SPORADIC E

UPPER ATMOSPHERE PHYSICS LABORATORY, AFCRL

Scientists of the Air Force Cambridge Research Laboratories and Cornell University have recently jointly conducted a series of experiments designed to learn more about dense, patchy layers of the ionosphere known as sporadic E.

Sounding rockets, which released a vertical chemiluminescent trail starting at 30 miles and extending to a peak altitude of 180 miles, and the 1000-foot Arecibo radar in Puerto Rico, were used to obtain precise data on ionospheric and wind conditions under which sporadic E forms.

A series of four rocket firings by a group led by Dr. N. W. Rosenberg of AFCRL were made from Camp Tortuguera, Puerto Rico. This was timed with simultaneous measurements made at Arecibo using a lower-ionosphere study program which has been developed over the past year by Merle LaLonde of Cornell University.

The rocket trajectory and radar beam intersected at a height of approximately 100 km, some 20 km north of Arecibo over the Atlantic Ocean. The measurements were made at night, and were spaced between sunset and sunrise on a night when sporadic E was detected by radio means at Arecibo. The particular night chosen required the cooperation of both local weather conditions for a clear observation of the trails and the mechanism which produces the sporadic E phenomenon.

Sporadic E occurs randomly and unpredictably, and affects both radio communications and radar detection--usually in a harmful way. Depending on radio or radar wave lengths, the signal is either absorbed or reflected, causing such effects as radar

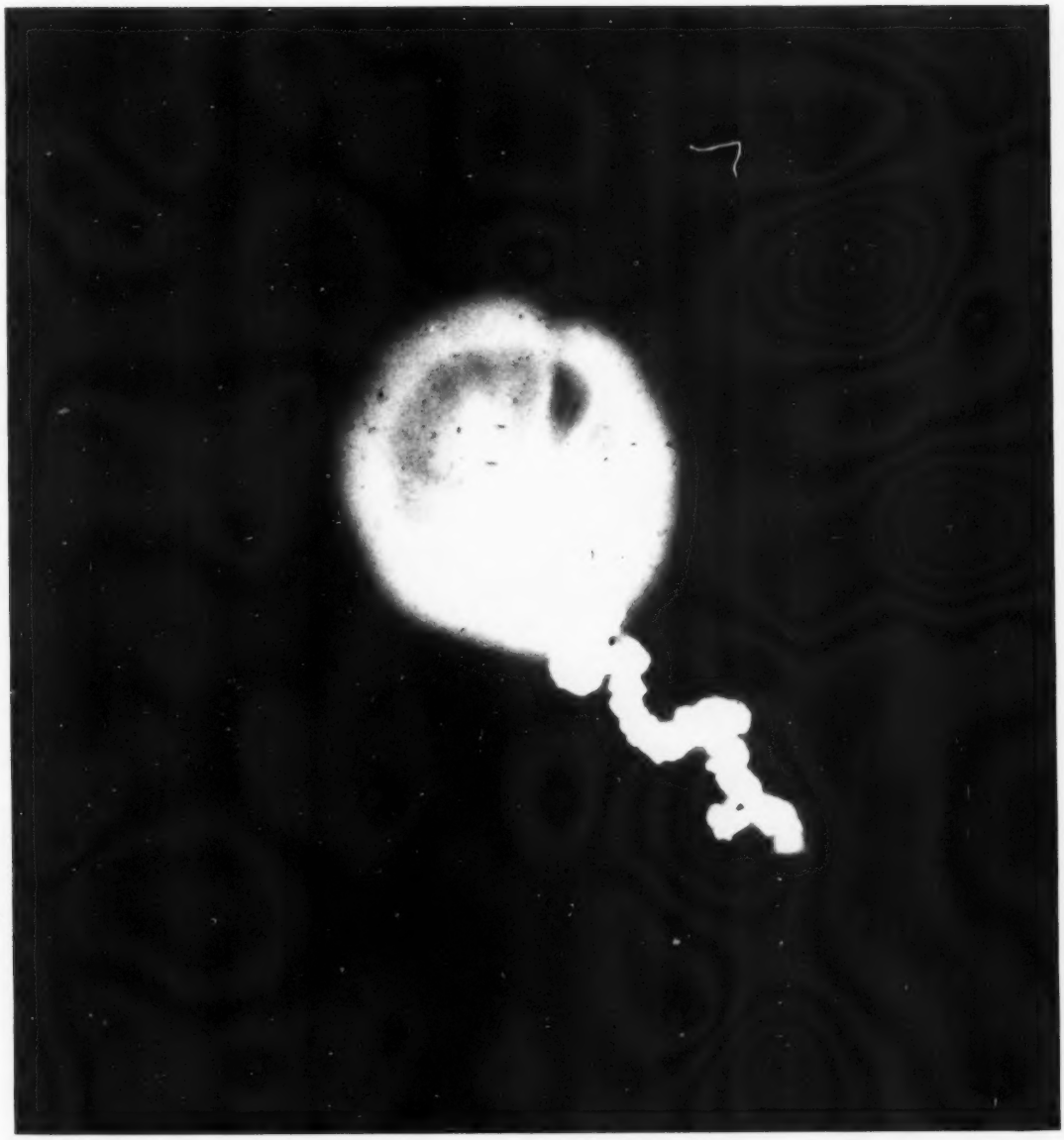


Photo 1. This is a picture of a chemiluminescent cloud showing the distortion effects of upper-atmospheric winds. One can barely discern in this photograph that the trail does in fact assume a helix-like configuration. The ballooning upper portion of the trail is due to the trail's expansion in the rare upper atmosphere.

clutter, signal fading, or the reflection of the signal over great distances.

Although sporadic E layers have been studied for many years, just how they are formed is not well understood. One promising theory, known as the "Wind Shear Theory," predicts that charged particles in the lower ionosphere will be forced to pile up into thin layers because the particles are moving relative to the earth's magnetic field. The mag-

netic field deflects the particles vertically, with the amount of deflection depending on the direction and velocity of the wind at any given altitude. Because the 100-to-150-mile-per-hour wind changes direction by 180 degrees at roughly 15-mile intervals, luminescent trails produced by rocket firings are distorted and assume a helical configuration. Thus, the moving charged particles cut across the lines of force of the earth's magnetic field at all angles, and are consequently deflected more strongly at given altitudes. This causes them to pile up at certain altitudes, thereby creating sporadic E.

To evaluate this theory, it is necessary to know more about wind shear--that is, the change in wind direction with altitude. High-altitude wind profiles are measured by releasing a luminescent chemical vapor from a rocket as it proceeds along a nearly vertical trajectory. These trails are tracked by cameras, and the height profile of wind magnitude and direction is obtained from the cloud motions as recorded on the films. ★

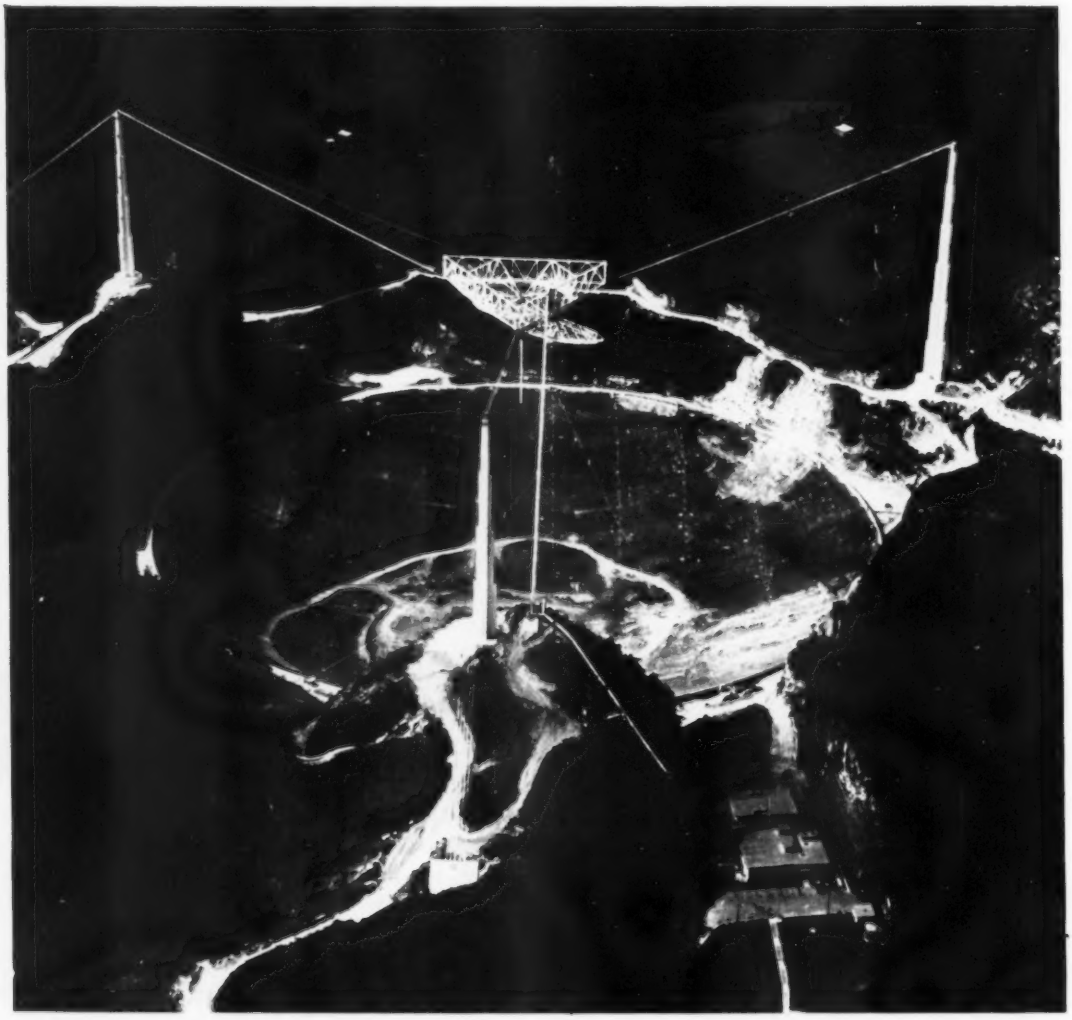


Photo 2. This is a standard view of the Arecibo Ionospheric Observatory which is an intrinsic part of the sporadic E test.

AFOSR chemists probe Air Force technical problems

DIRECTORATE OF CHEMICAL SCIENCES, AFOSR

The mission of the Air Force Office of Scientific Research (AFOSR), Office of Aerospace Research (OAR), is to sponsor basic research by awarding grants and contracts to support deserving unsolicited proposals. In the area of chemistry, the Directorate of Chemical Sciences, AFOSR, evaluates these proposals for scientific merit, novelty and import, originality, cost effectiveness, and significance to long-range Air Force objectives. Always a goal, the relevancy of basic-research programs to, and the feedback into, development programs of the Air Force is being increasingly reflected in these selections.

One approach in this direction was a recent conference in which selected Air Force development personnel and members of the Directorate of Chemical Sciences, AFOSR, intensively probed Air Force requirements to which chemical research might contribute. Their aim was to identify, by joint effort, the basic-research areas most likely to yield significant advances in terms of operational needs.

According to Dr. Amos G. Horney, AFOSR's Director of Chemical Sciences, "The purpose of this exploratory meeting was to help develop a clearer concept of new and outstanding chemical problem areas in the Air Force. We intend to include more applicable research in our future program, while maintaining the scientific merit and originality of the present program."

The conference, chaired by Dr. Horney, was attended by more than 25 representatives from various Air Force installations, 15 of whom spoke on selected topics. More important, the discussions brought to light specific technical requirements and promising areas for chemical research. Some of these are highlighted below.

Dr. J. T. Grey, Jr., Assistant to the President for Research and Development, Thiokol Chemical Corp, to start the ball rolling, spoke on the role of basic research in a mission-oriented organization, and the need for adequate communication between the research organization and the user commands.

Col D. R. Jones, Defense Intelligence Agency, discussed the intelligence requirements to which chemical technology may apply--specifically, the need for more sensitive sensors such as those for infrared, ultraviolet, and sound.

Col E. R. Davies, Deputy Chief, Biological-Chemical Division, Directorate of Armament Development, Air Force Systems Command, covered three main points: (1) synthesis of compounds with desired characteristics; (2) investigation of detectable body effluents for location of concealed persons; and (3) investigation of the chemistry and physics of fine material basic to the development of incendiary weapons.

Maj Jerome G. Bricker, Chemical and Biological program monitor, Weapons and Weapons Effects Division, Research and Technology Division, AFSC, pinpointed the need for rapid chemical methods for the detection of biological agents and binary biological agent techniques.

Mr. J. Paul Cali, Chief, Properties and Analysis Branch, Solid State Sciences Laboratory, Air Force Cambridge Research Laboratories, OAR, emphasized that new approaches are required for the determination of the light elements in electromagnetic materials. No satisfactory methods are presently available for the determination of such elements as O, N, or C in less than part-per-million amounts in semiconductor materials. These trace elements affect radiation resistances in electronic devices.

Mr. Frank Rehm, Group Leader in the Antenna and Coherent Optical Section, Rome

Air Development Center, AFSC, pointed out the need for more intensive investigation of the laser aspects of organometallic compounds and of spectral cross relaxation in neodymium glass media.

Mr. Karl Kyselka, Directorate of Armament Development, AFSC, discussed the requirement for an exploratory-development program directed toward advanced explosive systems--specifically, the development of an explosive to withstand a temperature of 350 degrees F for 15 minutes, and with about 1.25 the explosive force of TNT.

Lt Col George F. Babits, Chief, Propellant Division, Rocket Propulsion Laboratory, AFSC, spoke about low-molecular-weight metallic elements, such as Be, B, Al, and Mg, which are of current interest in high-energy propellant systems. Gaseous molecules such as H_2, F_2, O_2 and O_3 are the most interesting oxidizers, and the noble gases and their derivatives are now receiving emphasis. More investigation is needed on: (1) energetic species, including metastable atoms, ions, and molecules; free-radical, and unstable ions; (2) oxidizer structural studies - NMR (nuclear magnetic resonance), IR (infrared), UV (ultraviolet), EPR (electron paramagnetic resonance), and spectral studies of possible energetic rocket oxidizers; and (3) chemical kinetic studies--reaction-rate studies on chemical rocket propellant candidates.

Dr. H. A. Tanner, Assistant for In-House Research, Air Force Materials Laboratory, AFSC, discussed their research program, especially energy dissipation in solids and the surface phenomena of metals.

Dr. J. Bierlein, Chief, Chemistry Branch, Aerospace Research Laboratories, OAR, covered the ARL program and, in particular, current efforts on the separation of elements with gas chromatography.

Col Charles K. Arpke, Director, Chemistry Division, Frank J. Seiler Research Laboratory, OAR, highlighted FJSRL's research program and the research which cadets and faculty of the Air Force Academy are encouraged to perform.

Dr. Anthony J. Matuszko, program chief for organic chemistry, Directorate of Chemical Sciences, AFOSR, provided details on the AFOSR chemistry program. Research interest has developed recently in the better understanding of bonding between organic molecules and metals. This has resulted in at least three international symposia on organometallics in the past three months. Among Air Force interests in organometallics may be listed adhesion, polymerizations, propellant ingredients, and lasers. Significant contributions in organometallic chemistry in the AFOSR program were cited.

Dr. William L. Ruigh, program chief for inorganic chemistry, Directorate of Chemical Sciences, AFOSR, emphasized inorganic chemistry and new techniques in the AFOSR chemistry program. The program in phosphorus chemistry has resulted in both a general advance in the field and, more specifically, a marked advance in the gas-chromatographic detection and analysis of phosphorus compounds. An improved gas-chromatographic detector has been developed which will be of value in defense against toxic phosphorus gases. New techniques in infrared spectroscopy supported by AFOSR have led to the first chemical laser, thus providing a powerful new tool for studying high-speed chemical reactions.

Dr. Alfred Weissler, program chief for physical chemistry, Directorate of Chemical Sciences, AFOSR, provided details on the AFOSR program in physical chemistry, with special attention to the structure of matter and the interactions between energy and matter. This included photochemistry, radiation chemistry, and shock-wave and other high-temperature research. Chemical ultrasonics was pinpointed as a promising new field, with ramifications ranging from standard methods for evaluating the efficiency of ultrasonic cleaners used by the Air Force, to novel syntheses for propellants.

As the result of this conference and similar such efforts, AFOSR research in chemistry will reflect a steadily increasing emphasis on immediate and long-range Air Force technical problems. ★

PROFILES

Mr. K. S. Nagaraja, Hypersonic Research Laboratory, ARL, is currently concerned with studies of the physics of condensation, particularly with reference to wind-tunnel condensation in hypersonic flows. The shock structure problem and the transition from the noncontinuum to continuum flows also are being investigated, together with related problems in rarefied gas flows. Mr. Nagaraja has submitted the thesis for his Ph.D. (Aeronautical Engineering and Astronautics) at Rensselaer Polytechnic Institute, Troy, New York. In 1958, he received an Associateship of the Indian Institute of Science (A.I.I. Sc.), Bangalore, India. His M.S. in Mathematics was obtained in 1954 from Banaras Hindu University, India. His B.S. in Physics, Mathematics and Chemistry (1951), and his Diploma in Intermediate Science (1949) both were obtained from the University of Mysore, India. Mr. Nagaraja was awarded scholarships by the Government of India and the Indian Institute of Science for conducting theoretical studies in applied aerodynamics, particularly in wing design in subsonic and supersonic flows. He has also published many articles. In this issue of the Review, he writes on "The Linearized Rayleigh Problem According to Kinetic Theory."

Dr. Trice W. Haas is a task scientist in the Chemistry Research Laboratory, ARL. He is basically concerned with studies of the physics and chemistry of solid surfaces. One of the objectives is to prepare clean surfaces and to study their interaction with various gases. The interactions on the surface are studied by low-energy electron diffraction. This is coupled with a partial pressure analysis of the gases in equilibrium with the surface using standard mass spectrometric techniques. Another subject of current interest is the investigation of gettering properties of various evaporated metals under ultrahigh-vacuum conditions. Dr. Haas received his Ph.D. from the Iowa State University of Science and Technology (1960), and his B.S. from St. Mary's University (1954). Prior to coming to ARL in April 1964, he was a research chemist with the National Cash Register Company, and a senior research technologist with the Socony Mobil Oil Co. In this issue of the Review, Dr. Haas discusses "The Oxidation of Clean Molybdenum Surfaces."

The article, "Cosmic-Ray Trajectories," which appeared in the March 1966 issue of the Review, reflected work by Miss M. (Peggy) Ann Shea (left) and Mr. Don F. Smart (right), both with the Cosmic Radiation Branch, Space Physics Laboratory, AFCRL.

Miss Shea attended the University of New Hampshire, Durham, N.H., receiving in 1958 a B.S. in Physics from the College of Engineering, and in 1961 an M.S. in Physics. From July to October 1962, she worked as a physicist at the University of Hawaii, Honolulu, Hawaii and, from October 1962 until January 1964, as an associate scientist in the Geophysics Section of the AVCO Corporation, Wilmington, Massachusetts. Currently, as a research physicist at AFCRL, Miss Shea conducts investigations involving the behavior of solar-flare particle radiation, primary cosmic radiation, and intensity-time variations. She has a number of publications to her credit. Miss Shea is a member of the American Geophysical Union, the American Physical Society, and Sigma Xi.

Mr. Smart has a B.S. in Physics (1957) from Utah State University. He is presently taking graduate courses in physics in his spare time. After graduation from college, Mr. Smart worked for the U.S. Naval Ordnance Laboratory at Corona, California on guided-missile fusing until ordered to active duty as a Lieutenant in the Air Force. He was assigned to the Air Force Cambridge Research Center (now AFCRL), becoming project scientist for the IGY Project 1.24 at Thule, Greenland. After completion of his active duty in February 1960, Mr. Smart remained at AFCRL as a civilian physicist. Currently, he is Acting Chief of the Cosmic Radiation Branch. He has been working on the problems of the "optics" of cosmic radiation, including the asymptotic direction of approach allowed through the earth's magnetic field and cosmic-ray cutoff rigidities. He is further concerned with data-processing problems encountered in utilizing satellite vehicles for geophysical research. Mr. Smart is a member of the American Geophysical Union and American Association for the Advancement of Science.

Mr. John P. Castelli is Supervisory Research Electronics Engineer with the Radio Astronomy Branch, Space Physics Laboratory, AFCRL. He attended Boston College, Newton, Massachusetts where, in 1938, he received his A.B. (cum laude) in the Romance Languages. In 1939, he received his M.A. from the same college. During 1943-1946, Mr. Castelli served in the U.S. Army Air Forces as a radar officer. From 1946 to 1949, he was engaged in rocket instrumentation for the V-2 and aerobees. Currently, Mr. Castelli is project engineer for the Sagamore Hill Solar Radio Observatory, for microwave solar research, and microwave radio-astronomy research in the Space Physics Laboratory utilizing 1200 MHz through 35,000 MHz. He supervises the layout of the project, implementation of equipment, data collection, and analysis. Mr. Castelli led a group in Florence, Italy in 1961, and in Bangor, Maine in 1963 during total solar eclipses. Presently, he is preparing to conduct further eclipse experiments in Greece (May 1966) and in Peru (November 1966). He was author of the article, "Solar Radio Noise: Potential Index to Environmental Prediction," which appeared in the March 1966 Review.

First Lt. William F. King, III is a member of the Logic Technology Branch, Data Sciences Laboratory, Air Force Cambridge Research Laboratories. He received a B.S.E.E. with high honors from the University of Florida in 1963. Upon entering the Air Force, he was assigned to the Air Force Institute of Technology and was graduated from Stanford University with an M.S. degree in 1964. He is currently working in the area of modular sequential machine design. Also he is teaching advanced mathematics at Northeastern University. Lt. King is a member of Sigma Tau. In this issue of the Review, he describes a "Thin Magnetic Film Logic Device."

THE LINEARIZED RAYLEIGH PROBLEM ACCORDING TO KINETIC THEORY

K. S. NAGARAJA, Hypersonic Research Laboratory, ARL

Recent advances in the flights of missiles and space vehicles in regions far above the "dense" atmosphere have accelerated efforts toward understanding the basic flow phenomena in low-density regions. The aerodynamic problems associated with the flight of subsonic and supersonic aircraft in dense regions of the atmosphere can be analysed theoretically by using the so-called continuum equations. They are either the Navier-Stokes equations or equations of motion derived from them. The flow fields around bodies, either in flight or under laboratory testing conditions, are characterized by a large number of collisions (on the order of 10^{10} per second) among the molecules themselves. However, as the flight altitude is increased, the atmosphere becomes thinner, and the fluid medium can no longer be treated as a continuum. The degree of rarefaction of the medium can reach such a limit that free-molecule flow ensues which, by definition, is free of intermolecular collisions. However, the occurrence of a few intermolecular collisions in the free-molecule limit does not influence the macroscopic (or the average) flow field around a body surface. The aerodynamic forces on a body in a free-molecule flow are entirely due to the momentum and energy transfer resulting from the impact of the molecules on the surface.

The flow regime between the continuum and the free-molecule limits is known as the "transition region," which is characterized by the influence, in varying degrees, of both the molecule-molecule collisions and the molecule-body collisions. If the latter alone is dominant, the flow is near-free-molecular. The preponderance of the molecule-molecule collisions describes continuum or near-continuum flow.

One of the major problems in rarefied gas dynamics is the determination, theoretically as well as experimentally, of the flow characteristics in the entire transition region. It is evident that the Navier-Stokes equations cannot be used as a tool for analysis when the flow departs from continuum. A "global" equation which can predict the macroscopic behavior in the entire transition region, and which is derived on the basis of statistical mechanical and molecular interaction laws, has to be adopted. The classical Boltzmann equation (1) (written hereafter as B-equation) for electrically neutral particles which, on the one hand, predicts the free-molecular behavior and, on the other hand, yields the Navier-Stokes equations, has been successfully used for obtaining solutions in the neighborhood of free-molecular or continuum conditions. With the advent of high-speed computers, it has become possible, using the B-equation, to obtain solutions in the entire transition region, provided the problem can be suitably formulated.

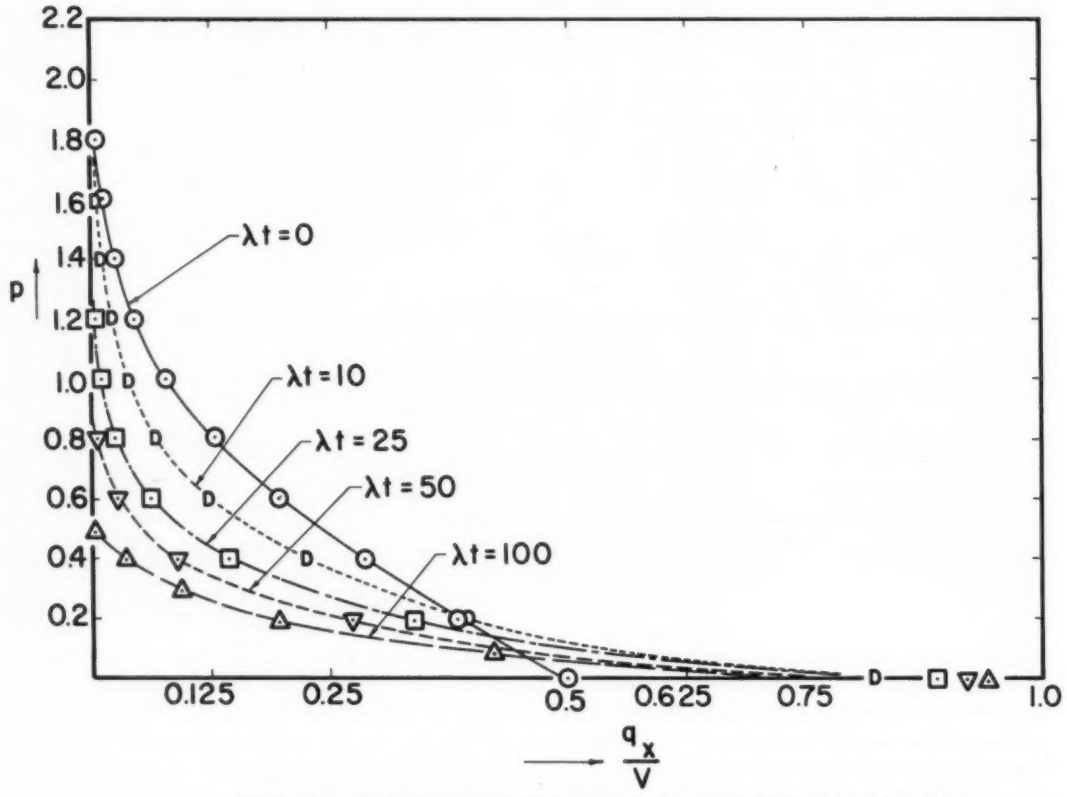
The unknown function (to be determined as a solution of the B-equation) is the velocity distribution function (or the probability function) which expresses the probability value of a certain number of molecules or particles being present in a given cell in "phase space." The two "classes" (or "species") of molecules which densely fill the phase space, each of which can be described by a characteristic distribution function, collide between themselves. The change in the number of molecules of one "class" in the cell due to collisions, together with the change in the same class in the cell due to flux, is shown to be equal in the B-equation to the time variation of the number of molecules belonging to the same class. The resulting integrodifferential equation is nonlinear and partial. Once the solution of this equation is obtained, subject to the appropriate boundary

conditions, the macroscopic (or the average) flow properties can be obtained by taking the higher moments of the velocity distribution function.

The collision-free flow is characterized by Maxwell's velocity distribution function which is of the form of the Gaussian probability distribution. The flow becomes non-isentropic when the velocity distribution function deviates from the Maxwellian. It is, therefore, necessary to consider the B-equation. However, as the equation is formidable, some approximation techniques become necessary in order to obtain the solutions.

The first method of solving the B-equation depends on perturbing the velocity distribution function around the Maxwellian; the solutions obtained in analytical form are generally valid in the neighborhood of the free-molecule or the continuum flow.

The second approach for solving the B-equation involves a modification of the collisional integral. One of the models which involves replacing the collisional integral in the B-equation is called the BGK model, or the so-called Krook model (2). The model has been widely discussed and its usefulness established by applying the BGK equation for solving the problems of Couette flow, the shock structure in a monatomic gas, transitional drag on a sphere, etc. Another simpler boundary-value problem, which is investigated by using the BGK equation, is the classical Rayleigh problem (3). The problem can be stated as follows: an infinite flat plate suddenly moves with an impulsive velocity V, which is small compared with the local speed of sound. The disturbance velocity as well as the shear stress in the flow field must be determined. The original Rayleigh solution was derived for an incompressible flow. However, subsequent works included



Velocity Profiles for Different Values of Collision Numbers

the effects of compressibility, and all of these solutions depended on Navier-Stokes equations.

The Rayleigh problem is an illustration of the unsteady, or transient, flow problems associated with suddenly accelerated bodies. The unsteady solutions not only provide an understanding of the growth and propagation of flow characteristics, but also determine the range and validity of the Navier-Stokes equations or the boundary layer equations (4). Howarth (5) has shown in his analysis of the Rayleigh problem that the steep pressure fall in extremely short intervals of time invalidates the use of the Navier-Stokes equations. He points out that an approach based on kinetic theory is desirable to obtain accurate solutions. The kinetic theoretic approach is also essential for obtaining the transitional behavior when bodies, such as space vehicles re-entering the atmosphere, traverse through regions of different densities. As a step in the direction of understanding the different problems involved, the simple Rayleigh problem is considered. The governing BGK equation is

$$\frac{\partial \tilde{\phi}}{\partial t} + \eta \frac{\partial \tilde{\phi}}{\partial y} = \lambda (\tilde{\phi}_o - \tilde{\phi})$$

where $\tilde{\phi}(\lambda, y, t, \xi, \eta, \zeta)$ is the molecular velocity distribution function; λ is a constant collision frequency, and t denotes time; $\tilde{\phi}_o$ is the equilibrium velocity distribution function which the system attains due to the intermolecular collisions; y refers to the axis normal to the plate surface, and the x-axis is along the plate surface and parallel to the direction of V; ξ, η, ζ are the molecular velocity components along the three co-ordinate axes (x, y, z), respectively. The probability functions of the incident and reflected molecules are assumed to be Maxwellian. The plate temperature T_w is the same as the undisturbed stream static temperature, T_∞. In view of the assumption that V is small compared with the local speed of sound, the density (ρ_o) remains constant, and the average velocity q_y in the y-direction is zero. Under these assumptions, the functions $\tilde{\phi}$ and $\tilde{\phi}_o$ are linearized as follows

$$\tilde{\phi} \simeq F(1 + \phi)$$

and $$\tilde{\phi}_o \simeq F(1 + 2\beta_o \xi q_x)$$

where F is the Maxwellian function of the undisturbed stream, $\beta_o = 1/2\,RT_\infty$ (R being the universal gas constant), and q_x is the average velocity in the x-direction. The linearized equation and the boundary conditions now are

$$\frac{\partial \phi}{\partial t} + \eta \frac{\partial \phi}{\partial y} = \lambda (-\phi + 2\beta_o \xi q_x) \quad \text{---} \quad (1)$$

$$\phi = 2\beta_o \xi V \quad (\eta > 0) \quad \text{at } y = 0 \quad \text{---} \quad (2)$$
$$\to 0 \quad (\eta < 0) \quad y \to \infty$$

Taking the moment of ϕ reduces the equation (1) under the boundary conditions (2) into a singular integral equation for q_x. The solutions q_x, evaluated on an IBM 7094, are shown in the accompanying graph.* It is seen that the velocity profiles for different collisional numbers lie between the limiting profiles; $\lambda t = 0$ corresponds to the free-molecule flow, and the slip-velocity then is V / 2; whereas, with increasing collisional numbers the slip-velocity decreases, and finally becomes zero in the Rayleigh limit. In other words, with increasing collisions, the ratio q_x / V increases to the limit of unity. On the other hand, an increase in the number of collisions decreases the "boundary-layer" thickness and, in the limit, the boundary-layer solution corresponds to the Rayleigh solution.

Further results, including an extension of the Rayleigh problem for obtaining the temperature distribution, are given in Reference (6).

*p is a nondimensional co-ordinate distance given by $p = \sqrt{\beta_o}\, y/t$.

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MATTHIESSEN'S RULE-ELECTRICAL RESISTIVITY OF SOME GOLD ALLOYS

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The study of the electrical resistivity of metals is one of the oldest subjects in solid-state physics. The topic, Matthiessen's rule,(1) is just over 100 years old. However, the continuing investigation of the electrical resistivity of metals still proves fruitful. Measurements can be made with great accuracy and, combined with our increasingly comprehensive knowledge of the solid state, prove to be a useful tool in the study of the ever-more subtle effects in solids.

According to Matthiessen's rule,* the electrical resistivity, $\rho(T)$, of a binary alloy is the sum of the temperature-dependent resistivity, $\rho_1(T)$, of the pure metallic solvent and a temperature-independent residual resistivity,** ρ_0, proportional to the concentration of the metallic solute or "impurity", i.e., $\rho = \rho_1(T) + \rho_0$. This relation is easily understood in terms of the simple Drude theory***. The current is carried by the valence electrons which are free to move through a metallic crystal. All of the electrons are supposed to have the same mass, speed, and mobility. The electrons are scattered both by the vibrations of the lattice and by the solute atoms. Since these scattering mechanisms are independent of each other, they contribute additively to the electrical resistance. Experimentally, Matthiessen's rule is found to be a good first approximation; however, significant deviations from the rule have been found. The measured values of the resistivity may be represented by $\rho(T) = \rho_1(T) + \rho_0 + \Delta(T)$.

A number of investigations, both experimental and theoretical, undertaken to explain the occurrence of the term Δ have achieved, at best, only partial success. Two nearly self-evident causes of deviations from Matthiessen's rule must be mentioned. The

*Matthiessen's rule is an approximate rule stating that the total electrical or thermal resistivity of a metal is the sum of the separate resistivities due to scattering of the electrons by thermal vibrations of the crystal lattice, by impurities, by imperfections, etc.

**Residual resistance is that part of the electrical resistance of a metal which is independent of the temperature and, hence, remains when the resistance due to scattering of the electrons by lattice vibrations is made small at low temperatures. Residual resistance is caused by impurities and imperfections in the crystal lattice and, hence, may be reduced by purification, annealing, etc.

***The Drude theory of electrons in metals expresses the original form of the free-electron theory of metals in which the electrons are treated as a gas of classical particles. This theory is capable of explaining the high electrical conductivity of metals, but attributes to them far too large a specific heat, and has to be supplemented by the postulate that the electrons obey Fermi–Dirac rather than Maxwell–Boltzmann statistics. According to the free–electron theory of metals, the conductivity of electrons in a perfect atomic lattice should be infinite. This is also true, in the band theory of solids, for an unfilled electronic band. However, the lattice is never perfect. It always contains imperfections and impurities, and is always in a state of agitation by thermal vibrations, which scatter conduction electrons.

addition of the solute to the solvent will change the spectrum of the lattice vibrations and will also change the concentration of electrons, particularly if the solute and solvent atoms have different valences. However, measurements made on very dilute alloys in which these effects should be minimal show that these changes cannot completely account for the deviations from Matthiessen's rule. Moreover, the Drude free-election theory is an oversimplification of the true situation in real metals. Deviations from Matthiessen's rule can occur because all the electrons do not have the same mass, speed and mobility. This effect is typified by the two-band model proposed by Sondheimer and Wilson. (2)

Koshino (3) has suggested that deviations from Matthiessen's rule may be caused by inelastic scattering of the electrons by the solute atoms. This idea has been discussed by Klemens (4) and Taylor. (5) Although the detailed theoretical calculations are rather formidable, a very simple picture of the effect can be drawn. The elementary calculation of the residual resistivity proceeds by treating the solute atom as a fixed center carrying an electrical-charge distribution different from that on a solvent atom. An electron can then be scattered by the electric field surrounding the solute atom. In such a scattering event, momentum can be transferred between the electron and the lattice; however, the energy of the electron is unaltered. In reality, the solute atom is always moving relative to its neighbors. The effect of this motion is to distort the electric potential surrounding the impurity and to make it time-dependent. This permits the occurrence of other scattering events (thus increasing the resistivity) in which not only momentum but also energy is transferred between the electron and the lattice. To give an equivalent description of the effect in terms of phonons rather than vibrations of the atoms, one could say that the electron is scattered by the solute atom with the simultaneous emission or absorption of a phonon.

Recently, Drs. D. H. Damon and P. G. Klemens, working at the Westinghouse Research and Development Center, reported (6)(7) the results of some AFOSR-sponsored investigations designed to discover the importance of inelastic impurity scattering. Many experimental results showed deviations from Matthiessen's rule, but there were no detailed studies on dilute alloys at low temperatures. Damon and Klemens undertook to test the theoretical prediction (4) that (a) inelastic electron scattering should lead to a component of resistivity in alloys proportional to T^4 at low temperatures, and (b) this component, which is proportional to T at high temperatures, should deviate from linearity when the solute atoms are substantially lighter than the solvent atoms.

According to Klemens the inelastic impurity scattering should make a contribution to Δ of the form $\beta(T)\rho_o$ with $\beta(T) \propto T^4$ if $T \ll \theta_D$ where θ_D is the Debye temperature.**** Measurements of the resistivity of a number of gold alloys containing either Cu or Pt as solutes were made between 2 and 40°K (See Figure 1). Below about 16°K ($\sim\theta_D/10$) it was found that Δ could be represented by $\Delta = \alpha\rho_i + \beta\rho_o$ with α nearly independent of temperature and $\beta \propto T^4$ (See Figure 2). Furthermore, the values of α and β were the same for both solutes. The first term can be explained by using the previously mentioned two-band model. Very roughly, the electrons in gold can be divided into two groups (i.e., two "bands") with distinctly different properties. These two "bands" are in reality different parts of the complex Fermi surface of gold. The second term suggests that inelastic impurity scattering is indeed important. The magnitude of β is about five times larger than would be suggested by a simple theoretical model.

****Debye temperature is a parameter having the dimensions of temperature appearing in the Debye theory of specific heat. It is defined by the relation $\Theta = \frac{h\nu}{k}$ where ν is the maximum frequency of the thermal vibrations of the lattice, h is Planck's constant, and k is the Boltzmann constant. The symbol Θ is also used somewhat indiscriminately in various other contexts (e.g., electrical conductivity of metals) where it really should be defined differently, and may have a somewhat different value.*

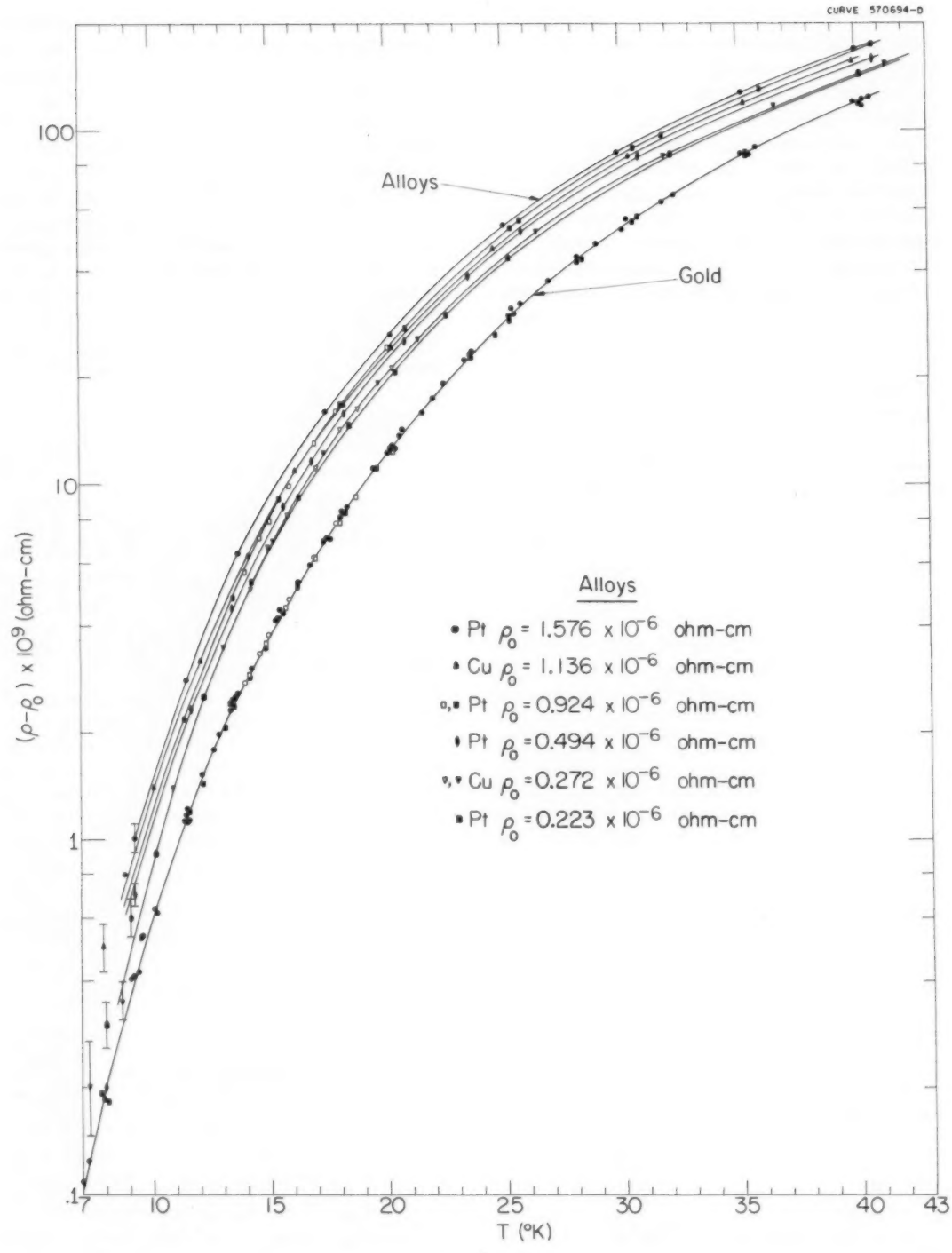
CURVE 570694-D
100
10
1
.1
Alloys
Gold
Alloys
• Pt ρ_0 = 1.576 x 10^{-6} ohm-cm
▲ Cu ρ_0 = 1.136 x 10^{-6} ohm-cm
□,■ Pt ρ_0 = 0.924 x 10^{-6} ohm-cm
◗ Pt ρ_0 = 0.494 x 10^{-6} ohm-cm
▽,▼ Cu ρ_0 = 0.272 x 10^{-6} ohm-cm
◆ Pt ρ_0 = 0.223 x 10^{-6} ohm-cm
$(\rho-\rho_0) \times 10^9$ (ohm-cm)
7
10
15
20
25
30
35
40
43
T (°K)

Fig. 1.

At high temperatures, $T > \theta_D$, phonon-assisted impurity scattering should result in values of Δ proportional to T. Such deviations from Matthiessen's rule are frequently observed, but need not necessarily arise from this cause. For example, over a 100 to 200°K range of temperatures for samples with ρ_i and ρ_o of the same order of magnitude, the two-band model would also predict that Δ should be roughly proportional to T.

In order to investigate the importance of inelastic impurity scattering at high temperatures, Damon and Klemens carried out another series of measurements in which they made use of the special vibrational properties of light mass impurities in a heavy mass solvent. A light atom in a crystal of heavy atoms can vibrate with a frequency, f_o, considerably higher than the Debye, or cutoff frequency, f_D. This vibration cannot propagate through the crystal and is called a local mode. Most of the local strain field surrounding the impurity (which is a measure of the relative displacement of the impurity and thus determines the strength of the inelastic impurity scattering) is associated with the local mode. If measurements of the resistivity of Au containing Al ($f_o \approx 3f_D$) were made from a temperature of $\sim\theta_D/2$ ($hf_D = k\,\theta_D$) to a temperature corresponding to the local-mode frequency, $T_o = \frac{hf_o}{k}$, one might expect Δ to increase faster than linearly with T since, over this temperature range, the local mode would change from being only feebly excited to being fully excited. Since there are other possible causes of deviations from Matthiessen's rule, a conclusion could only be reached through a comparison of the resistivities of alloys with different solutes and thus different local-mode frequencies.

Measurements of the resistivity of Au alloys containing either Al, Cu ($f_o \approx 2f_D$), Zn ($F_o \approx 2f_D$) or Pt (no local mode) were made between 80°K ($\sim\theta_D/2$) and 500°K (See Figure 3). The results showed no systematic differences that could be ascribed to phonon-assisted impurity scattering via the local modes, though there were substantial deviations due to other causes, probably the "two-band" effects.

The measurements at higher temperatures are inconclusive. One cannot say that inelastic impurity scattering is absent at higher temperatures, since it may be overshadowed by other effects. At low temperatures, however, where the overlapping factors are less complicating, the presence of strong inelastic scattering has been established.

Although it is believed that the electrical resistivity of metals and alloys is, in the main, understood today, there are many minor effects which still await an explanation. The latter can, in principle, throw light on the electronic and vibrational properties, if only theoretical understanding can be adequately refined. ★

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Fig. 1. Values of $\rho - \rho_o$ vs. T. For each specimen, ρ is the total electrical resistivity and ρ_o is the residual resistivity. A log scale is used for $\rho - \rho_o$ and a linear scale for T only for convenience in displaying the results. The lower curve shows the behavior of two pure-gold specimens whose residual resistivities were 7.79×10^{-9} and 9.10×10^{-9} ohm-cm. The upper curves show the results for the alloys and are distinguished in the legend. Open symbols show the results obtained using hydrogen vapor pressure as a thermometer; the full symbols show the results obtained using Au-Co thermocouples for thermometers. With the exception of the specimen with $\rho_o = 0.223 \times 10^{-6}$ ohm-cm, the residual resistivity of each of the other samples was independent of temperature between 1.3 and 4.2°K. The resistivity of this exception showed a slight minimum so that its ρ_o is somewhat uncertain. For the two pure-gold specimens, it is assumed that $\Delta = \rho - \rho_o - \rho_i = 0$, i.e., $\rho - \rho_o = \rho_i$ where ρ_i is the ideal resistivity of pure Au. Below about 10°K, ρ_i is very nearly proportional to T^5; however, ρ_i is not exactly proportional to any power of T even over the restricted range $7° < T < 16°K$. The results clearly show that $\Delta > 0$ for the alloys, and that Δ is an increasing function of ρ_o.

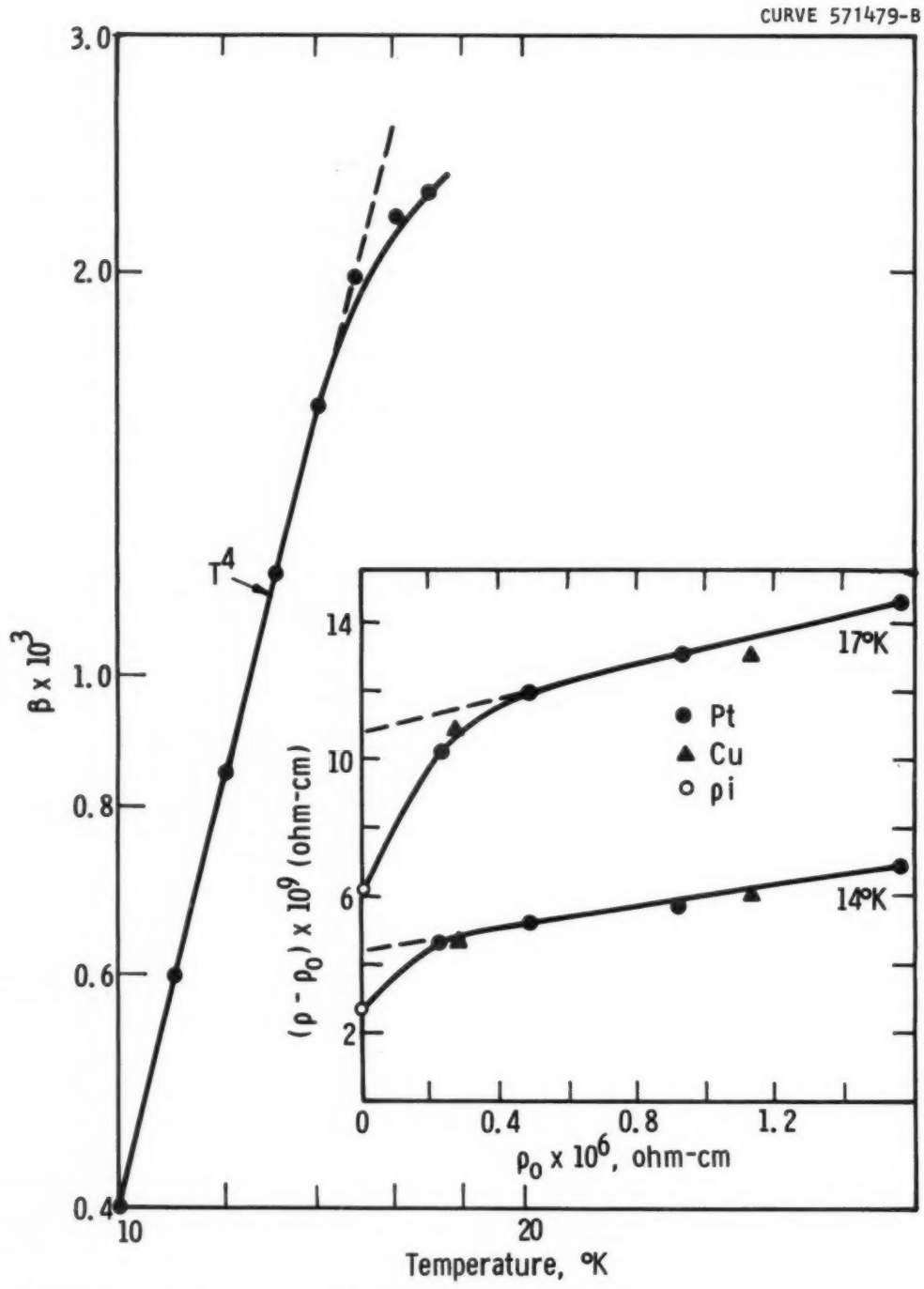

Fig. 2. The insert shows $\rho - \rho_o$ plotted against ρ_o at 14 and 17°K. The results show that $\Delta = \rho - \rho_o - \rho_i$ as a function of ρ_o is equal to (constant + $\beta\rho_o$) if $\rho_o > \sim 80\ \rho_i$. The constant is equal to $\alpha\rho_i$ with α only feebly temperature-dependent for $T < 16°K$. The main portion of the figure shows β as a function of T. It is clear that $\beta \propto T^4$ for $T < 15°K$.

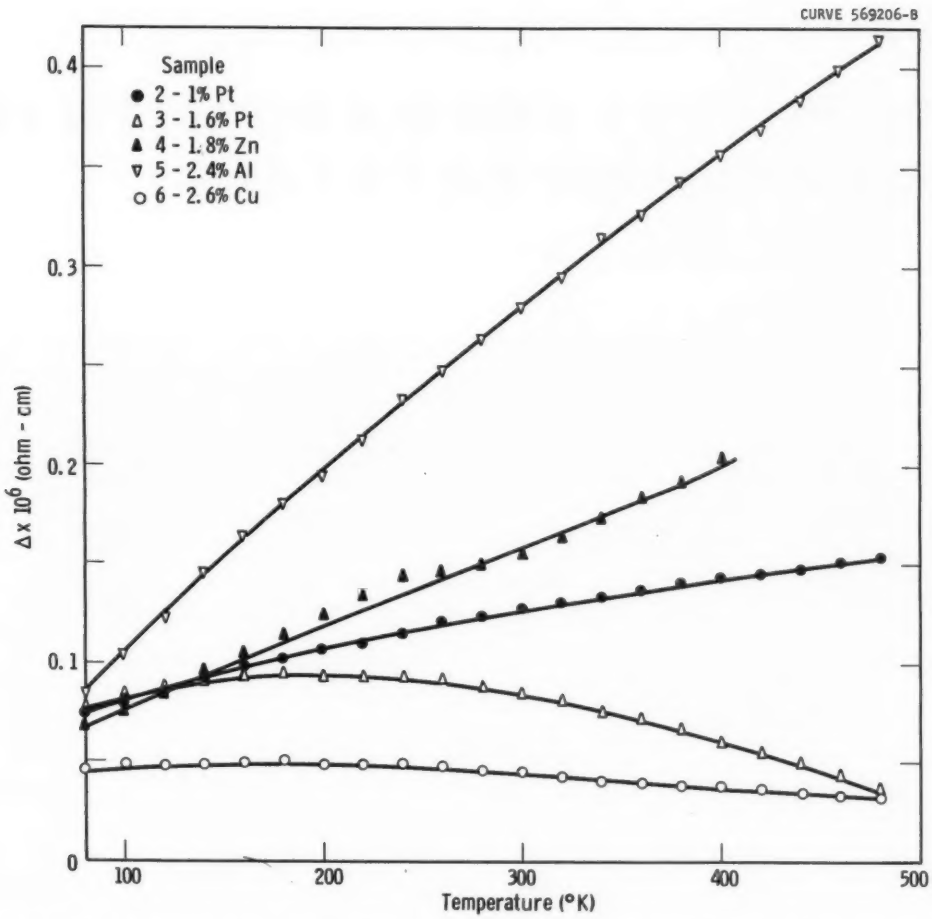

Fig. 3. Values of $\Delta = \rho - \rho_i - \rho_o$ for the gold alloys measured at high temperature. Again, ρ is the total electrical resistivity, ρ_i the ideal resistivity of pure gold, and ρ_o is the residual resistivity measured at 4.2°K. The legend identifies the alloys and shows the solute and its concentration in atomic percentage.

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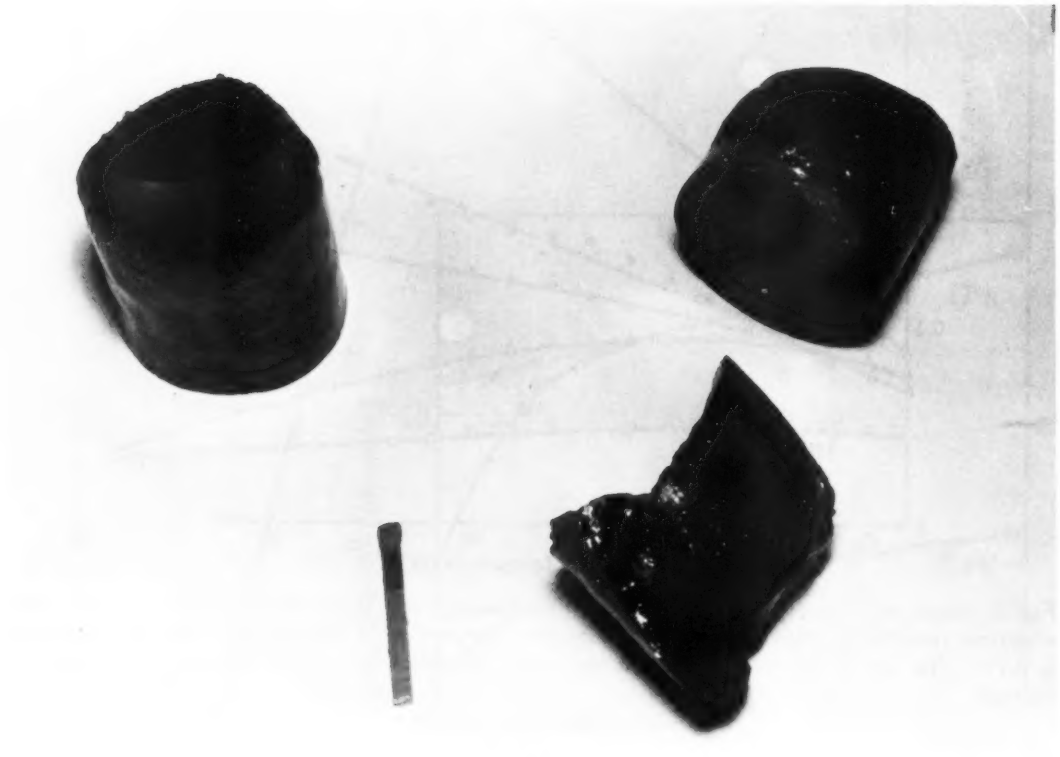
ARL PUSHES FORWARD WITH ITS RESEARCH ON CRYSTALS



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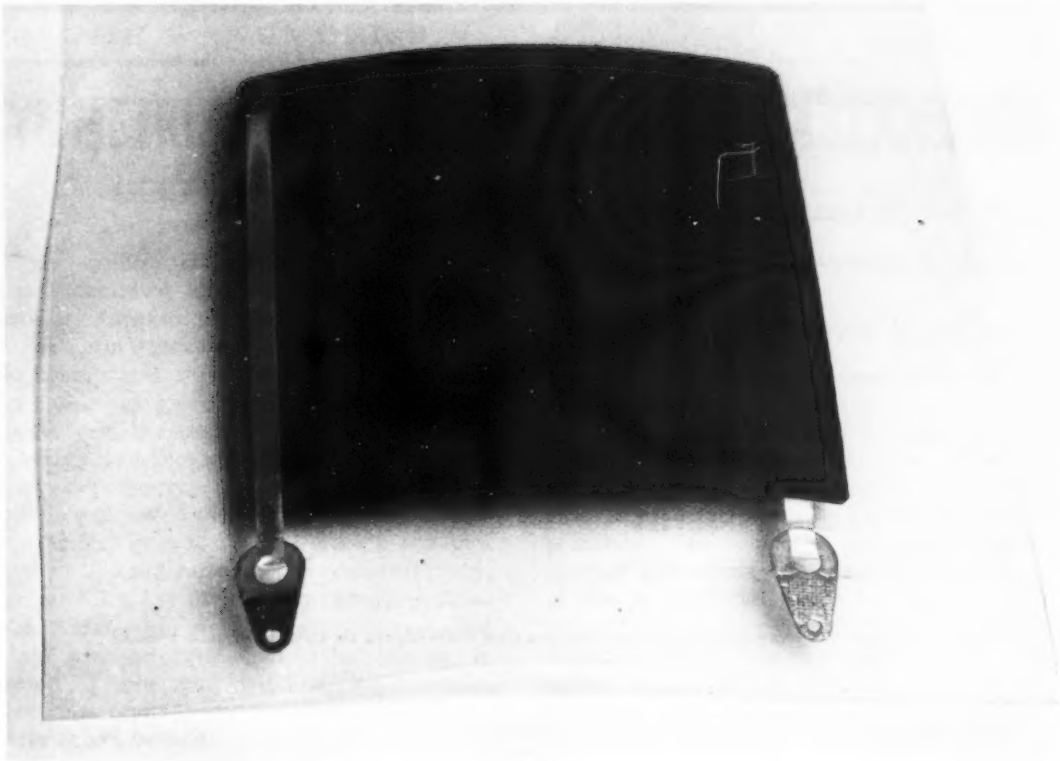

2

1 *Single CdS crystals grown at ARL. In addition to bulk crystals of cadmium sulfide, the Solid State Physics Research Laboratory also grows platelet and whisker-type crystals. These crystals are inherently of higher purity than bulk crystals. The mechanical properties of these crystals also indicate that they are far superior to bulk crystals with respect to lattice defects.*

2 *CdS film (solar) cell measuring 2 3/4" x 2 3/4". It has an open circuit voltage of 0.5 volts and a short circuit of 0.52 amps. These characteristics were measured in sunlight at an intensity of 1000 watts/m^2. Cells of this type have been produced at ARL's Solid State Physics Research Laboratory with power-to-weight ratios of 33 watts per lb.*

TO OUR READERS

Request for further information should be directed to the individual or laboratory of origin (except for those from Latin America).

Addresses are as follows:

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Attn: CRI
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AEROSPACE RESEARCH LABORATORIES
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THE FRANK J. SEILER RESEARCH LABORATORY
USAF Academy, Colorado 80840

OFFICE OF RESEARCH ANALYSES
Attn: ORR
Holloman AF Base, New Mexico 88330

Request for further information from institutions and individuals in Latin America should be addressed to:

LATIN AMERICAN OFFICE AEROSPACE RESEARCH
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